Dynamic Impacts of a Shock in Crude Oil Price on Agricultural Chemical and Fertilizer Prices

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A monthly vector autoregression (VAR) model of the following prices was estimated over the 1962:1–1990:6 period: crude oil price (CRUDE), industrial chemical price (INDCHEM), agricultural chemical price (AGCHEM), and fertilizer price (FERT). The VAR was shocked with a rise in CRUDE, and dynamic impulse response patterns in AGCHEM and FERT were observed. Results suggest that AGCHEM and FERT responses would be increases; would be mild for half a year; would thereafter gain in strength and peak within 19 to 21 months; and would last for 2.0 to 2.3 years. AGCHEM and FERT would rise by about one-fourth of the percentage increase in CRUDE which occurs over the response period.

World prices of crude oil doubled from July 1990 levels (approximately $20/barrel) within five weeks of Iraq's August 2, 1990 invasion of Kuwait. Thereafter, prices have substantially fallen from these peak levels, but have nonetheless fluctuated noticeably, with the progress of the Allied military build-up and with

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the course of Operation Desert Storm. Analysts have consequently increased attention to crude oil price movements and how these price ups and downs influence petroleum-based input prices in the economy.[1] This paper discerns the dynamic impacts that crude price fluctuations have historically had on the prices of agriculture's most important petroleum-based inputs: agricultural chemicals and fertilizers. Over the 1985–1989 period, agricultural chemicals and fertilizers have accounted for 8 to 9% of agricultural production expenses and for 58 to 60% of manufactured input expenses.[2] This article maps the historical dynamic impacts that crude oil price movements have had on agricultural chemical and fertilizer prices.

This study employs a monthly vector autoregression (VAR) model of the following four price indices to ascertain the nature of the historical dynamic interrelationships in the wake of a crude price change (here, an increase): domestic crude oil price (CRUDE); industrial chemical price (INDCHEM); agricultural chemical price (AGCHEM); and fertilizer price (FERT). The sample period was January 1962 through June 1990 (i.e., 1962:1–1990:6). The VAR model was shocked with a rise in crude oil price. Dynamic response multipliers were then obtained for AGCHEM and FERT. We pose five specific dynamically oriented questions (below) concerning the CRUDE/INDCHEM/AGCHEM/FERT price transmission, which captures the patterns of how these four variables have moved together historically. Answering such questions about historical dynamic relationships can provide insight on how history would handle any recently observed and any future crude price shocks, be these shocks increases or decreases, in terms of effects on AGCHEM and FERT. Results are valid insofar as the model's embedded long-run trends are similar to conditions surrounding recently observed or future crude price shocks. Within the context of a CRUDE shock (increase), the questions focused upon are: (a) what are the reaction times and directions of the AGCHEM and FERT responses?; (b) what dynamic patterns do the AGCHEM and FERT responses take?; (c) to what degree do AGCHEM and FERT respond to CRUDE?; (d) how long do the AGCHEM and FERT responses last?; and (e) what are the strengths of relationships among the modeled crude/chemical/fertilizer prices?

VAR ECONOMETRICS AND THE ESTIMATED VAR MODEL

Answering the above five questions about agricultural chemical and fertilizer price responses to shocks in crude oil price involves analysis of the dynamic price linkages mentioned above. That is, these dynamic issues concern what happens BETWEEN the pre- and postshock equilibria, and not so much with what happens AT the pre- and postshock equilibria. More conventional econometric models that intensively use static economic theory are better-equipped to handle questions concerning what happens at the static equilibria before and after the shock. Such *structural* econometric models often say little or nothing about what dynamically occurs between the equilibria to the observed choice variables—here agricultural chemical and fertilizer prices.[3] And the issues reflected by this study's addressed questions [(a) through (e), above] concern more of what dynamically happens between the equilibria before and after shocks in CRUDE. VAR econometrics better handles these dynamic interequilibria issues because the technique is a data-oriented one that imposes as few *a priori* theoretical restrictions as possible, so as to permit the dynamic regularities in the time-ordered data to reveal themselves (see Ref. 3).

Detailed summaries and derivations of VAR methods have been repeatedly presented in the literature, and this study does not undertake to provide another presentation. For such summaries and derivations, one should consult Sims,[4] Bessler,[3] and VanTassell and Bessler.[5] Hence, the VAR in Eq. 1 is a four-equation model, where each equation takes the form of Eq. 1.

$$\begin{aligned} x_t = a_{0_x} &+ a_{x,T}{*}\mathrm{TRD} + a_{x,1}{*}\mathrm{CRUDE}_{t-1} + \cdots + a_{x,14}{*}\mathrm{CRUDE}_{t-14} \\ &+ a_{x,15}{*}\mathrm{INDCHEM}_{t-1} + \cdots + a_{x,28}{*}\mathrm{INDCHEM}_{t-14} \\ &+ a_{x,29}{*}\mathrm{AGCHEM}_{t-1} + \cdots + a_{x,42}{*}\mathrm{AGCHEM}_{t-14} \\ &+ a_{x,43}{*}\mathrm{FERT}_{t-1} + \cdots + a_{x,56}{*}\mathrm{FERT}_{t-14} + R_t \end{aligned} \tag{1}$$

Above, the t subscripts represent period t, with $t - i$ being the ith lag from period t. The T represents the coefficient on the time trend or TRD. On the left hand side, x = CRUDE, INDCHEM, AGCHEM, and FERT. The R variable is the stochastic error term. The coefficient with a naught subscript represents the intercept.

Following VanTassell and Bessler,[5] the VAR model's lag structure was chosen using Tiao and Box's[6] likelihood ratio test procedure. The results (not reported here) suggest, at the 1% significance level recommended by Lutkepohl,[7] a 14-order lag structure for the VAR model. Each equation includes a constant, a time trend to account for time-dependent influences not of direct interest to this study, and a series of 11 indicator variables to account for seasonal influences.

Monthly producer price indices (PPI's) were obtained from the US Bureau of Labor Statistics. The PPI for crude petroleum (domestic production) serves as CRUDE. The PPI's for industrial chemicals and for agricultural chemicals serve as INDCHEM and AGCHEM, respectively. The PPI for mixed fertilizers reflects FERT. Eleven monthly indicator variables account for seasonal influences. Data were transformed to natural logarithms so that shocks to, and impulse responses in, the modeled price indices represent percentage changes in the nonlogged indices.*

The four VAR equations may have contemporaneously correlated innovations. Failure to correct for contemporaneously correlated current errors will produce impulse responses not representative of historical patterns.[4] A Choleski decomposition was imposed on the VAR to orthogonalize the current innovation matrix, such that the variance/covariance matrix is identity. The Choleski decomposition resolves the problem of contemporaneous feedback.

The Choleski decomposition sometimes requires an arbitrary imposition of a

*When exogenous events such as the August 1990 invasion of Kuwait results in crude oil price shocks (increases, here), one has the option of conducting this study with nominal or deflated CRUDE, INDCHEM, AGCHEM, and FERT. Much of the public, and presumably many agribusiness agents not directly involved with research, often focus upon nominal prices. Researchers often focus upon deflated prices in research, but also read about nominal price movements in the media. This journal has readers in both the research and the nonresearch camps. So we conducted the analyses with both nominal prices and deflated prices, but space considerations precluded reporting both sets of results. Yet both studies generated very similar results. Because the results were similar, we decided to report the results from the study on nominal prices, in order to provide results to the widest readership.

Wold causal ordering among current values of the dependent variables (see Ref. 3). VAR ordering is often based on *a priori* belief that the sequence represents a causal ordering of response. The chosen ordering was from CRUDE to INDCHEM, from INDCHEM to AGCHEM, and from AGCHEM to FERT. The ordering was based on three considerations. First, CRUDE was the ordering's initial variable because CRUDE's initial position itself reflects an obvious line of causality for the three remaining petroleum-based prices. That is, CRUDE is an input price for chemicals (industrial and chemical) and for fertilizers. Second, industrial chemical price precedes AGCHEM in the ordering because the industrial price is the broader of the two petroleum-based chemical price aggregates. And third, fertilizer price is the fourth price because FERT was the most specifically defined and the least aggregated price index of the three modeled non-CRUDE, but petroleum-based, input prices.

Fuller[8] and Dickey and Fuller (see Refs. 9 and 10) developed a stationarity test, whereby one regresses a variable's first differences against a constant and the nondifferenced variable lagged one period. Engle and Granger[11] recommend an augmented form of this test—the augmented Dickey–Fuller or ADF test. The ADF test includes a specified number of lagged dependent variables (i.e., lagged differences) with the Dickey–Fuller test regressors. Alternative lag selection procedures, such as Hsiao's application of Akaike's method based on minimized final prediction error, are often used to determine the ADF test's number of lagged dependent variables.[12] One rejects the null hypothesis of nonstationarity, and concludes that evidence suggests stationarity, when the pseudo-t value on the nondifferenced lagged regressor is both negative and of an absolute value exceeding 2.89 (Ref. 8, p. 373, 5% significance, t_μ values). The statistic is called a "pseudo"-t value because, while it is calculated as a Student t statistic, the value is not distributed as a Student t distribution.

Evidence suggests that the estimated VAR model is stationary at the 5% significance level. ADF tests were conducted on the four sets of residuals generated by the VAR equations. The four pseudo-t values are negative and have absolute values falling within the 11.98 to 12.88 range.

THE PRICE IMPACTS OF A CRUDE PRICE SHOCK

The impulse response function simulates, over time, the effect of a one-time shock on itself and on other series in the system. Such is done by converting the VAR model into its moving average (MA) representation. The MA representation's parameters are complex, nonlinear combinations of the AR regression coefficients.

Recall the five questions posed above concerning the dynamics of the modeled price transmission mechanism. It is of interest to know how agricultural chemical and fertilizer prices react over time. Do the responses for AGCHEM and FERT respond immediately or after a passage of time? Do the AGCHEM and FERT responses quickly fade out, or do they endure for a long period of time? Do the response patterns of AGCHEM and FERT which follow the crude oil price increase differ in terms of response reaction times, directions, durations, patterns, and in response strength levels?

Figure 1 presents the impulse responses in AGCHEM and FERT from imposition of a first-period shock (rise) in crude oil price. INDCHEM impulses are not

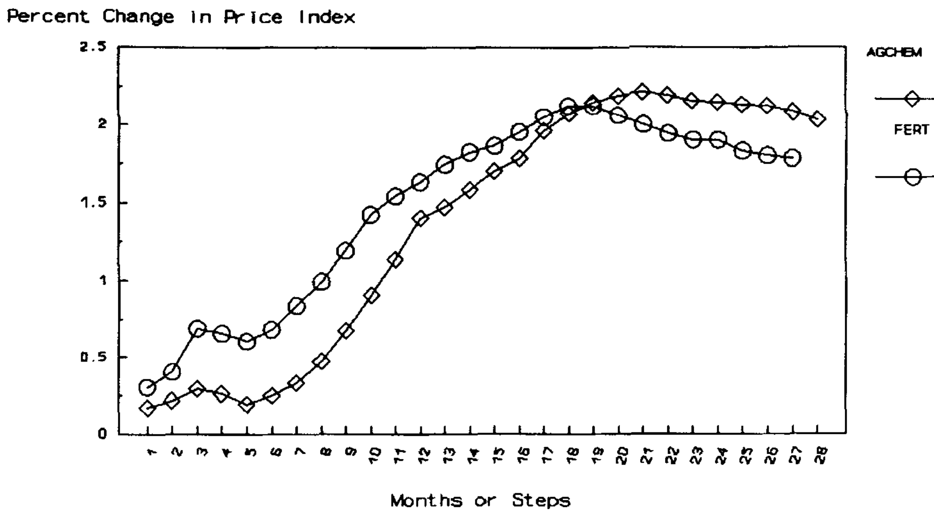

Figure 1. Agricultural Chemical and Fertilizer Price Responses to a 3.6% Increase in Crude Oil Price. Impulses Are Percentage Changes in Nonlogged Index Levels, and Are Statistically Non-Zero at the 5% Significance Level.

analyzed because this study's analytical purpose emphasizes price effects of the CRUDE increase on *agricultural* oil-based prices.† A 3.6% crude oil price increase was chosen because this increase equals one standard error of CRUDE's historical innovation, and hence is a normally sized shock in terms of the sample's historical patterns. The model is linear, such that shock size is arbitrary. A differently sized shock would generate the similarly shaped impulse response patterns as in Figure 1. Only the scales of Figure 1 would change for the AGCHEM and FERT responses from a differently sized CRUDE shock. Because the VAR model is linear, these base patterns and dynamic multipliers (discussed below) can be extrapolated for any sized shock by the appropriate scaler constant, as well as for combinations of shocks (positive and negative).‡

Impulse responses are changes in the natural logarithms of the index levels, and hence represent approximate percentage changes in the non-logged indices. Kloek and Van Dijk's[13] Monte Carlo procedure generated t values for each impulse response. One rejects the null hypothesis of a zero-valued impulse response, and concludes that the impulse is statistically non-zero, at the chosen

†INDCHEM was included to capture the nonagricultural chemical price movements, which are interrelated with agricultural chemical price movements, because of the common dependence of INDCHEM and AGCHEM on petroleum as a basic input.

‡Further, the VAR model is linear, so handling shocks that span more than one month entails adding together, at each step, the concurrent impulses of those CRUDE shocks which span more than one month. The model's linear nature implies symmetrically shaped, but oppositely signed, impulse response patterns of Figure 1 for CRUDE decreases. Should crude oil price rise and then decline the next month, then one looks at the series of *net* changes or impulses in CRUDE. These net impulses are obtained from adding the concurrent impulses, at each step, of the two shocks (positive impulses from the CRUDE increase and negative impulses of the CRUDE decrease). So this study's results can be used to analyze CRUDE increases and decreases, as well as shocks which span more than a single month.

significance level when the t value's absolute value exceeds that of the critical value. The figure includes only those impulse responses that were statistically non-zero at the 5% significance level: the first 28 AGCHEM impulses and the first 27 FERT impulses. [Note that after the 27–28 month period of significant impulses, the impulses lose significance and begin falling in magnitude through time.]

When crude price increases, prices of agricultural chemicals and of fertilizer rise immediately, that is, during the same month.[§] Yet the AGCHEM and FERT impulses are initially mild for about half a year, thereafter gain strength and peak in magnitude at 19 to 20 months, and endure ultimately for 27 to 28 months.

Note that after a one-time first-period shock in crude price, all four equations are set into motion, including CRUDE, the shock variable. Data levels were modeled in natural logs, such that the impulse responses in logs represent approximate percentage changes in non-logged levels. Babula and Bessler[14] demonstrate that a dynamic multiplier may be constructed. One need only to sum a response variable's (AGCHEM's or FERT's) impulses over the period of significance (27–28 months) to obtain a cumulated change in the response variable; sum-up the corresponding impulses in the shock variable to obtain a corresponding cumulative change in the shock variable; and then divide the response variable's change over the shock variable's change to obtain a dynamic sensitivity parameter, or DSP. This DSP is a dynamic multiplier that resembles an elasticity, insofar as it is a percentage change in the response variable over a percentage change in the shock variable defined for the response variable's period of impulse significance. The DSP differs from an elasticity in being defined over a multi-period horizon and not, as an elasticity, for a point in time.

Nonetheless, the DSP of a response variable to change in the shock variable provides a dynamic multiplier which demonstrates strength of response (see Ref. 14). The DSP represents the amount, in percentage terms, that history would have the response variable (AGCHEM or FERT) respond per percentage change in the shock variable, CRUDE, over the period of impulse statistical significance (28 months for AGCHEM and 27 months for FERT).

The DSP for agricultural chemicals price is 0.24. So history would have each percentage point rise in crude oil price elicit about a quarter of that change, 0.24 of a percent, in agricultural chemical prices, and such responses would occur over 2.0 to 2.3 years.

The DSP for fertilizer price is 0.25. History would have each percentage point rise in crude oil price elicit a quarter of that change in fertilizer prices, and such responses would also occur for 2 years or more.

So history states that whatever the realized CRUDE shock from, say, the Persian Gulf crisis (3.6% or perhaps 100%), AGCHEM and FERT prices would be expected to rise immediately but mildly for half a year; gain in strength and endure for 2.0 to 2.3 years; and increase by about one-quarter of the realized CRUDE price percentage increases.

[§]The word *immediately* should be used cautiously here because the model and data have a monthly periodicity. A variable's response can therefore take up to almost a month or nearly 3 to 4 weeks to respond to a shock which occurs very early in the month, and still be considered immediate. So an immediate reaction time has responses commence within the same month as the shock, which can entail up to 29 days.

DECOMPOSITIONS OF FORECAST ERROR VARIANCE

Analysis of decompositions of forecast error variance (FEV) identifies the interrelationships within the modeled system's time series (see Ref. 4). The FEV is, at alternative forecast horizons or steps, attributed to shocks in each of the dynamic system's series, such that a measurement of relative strength of relationships emerges. Error decompositions attribute within-sample variance to alternative series and thus provide a measure useful in applied work.[3] Table 1 provides the FEV decompositions for three of the four modeled prices. Because of space considerations, we have deleted the FEV decompositions for INDCHEM because this variable is not focused upon in this study.

The relative strength of influence that one variable has on another over alternative time horizons is also of interest to researchers and agribusiness agents who wish to examine the modeled crude oil/chemicals/fertilizer price transmission. This is summarized through decomposition of forecast error variance (FEV). For example, consider the agricultural chemical price. Of the uncertainty in

Table I. Decompositions of Forecast Error Variance (FEV).

			Percentage Explanation of Forecast Error Variance from			
	Step	Standard Error	CRUDE	INDCHEM	AGCHEM	FERT
Crude Oil Price, CRUDE	1	0.0641	99.85	0.08	0.03	0.04
	3	0.1071	96.41	0.13	0.56	2.90
	6	0.1631	90.43	1.78	0.75	7.04
	12	0.2350	80.00	4.65	0.39	14.97
	18	0.2854	75.02	8.65	0.48	15.86
	24	0.3399	72.52	10.36	0.68	16.45
	30	0.3855	71.10	10.94	0.84	17.11
Agric. Chemical Price, AGCHEM	1	0.0160	2.91	1.03	95.58	0.49
	3	0.0251	3.63	5.21	85.68	5.47
	6	0.0376	3.08	18.01	69.76	9.15
	12	0.0798	11.50	20.28	35.85	33.37
	18	0.1249	18.32	12.31	26.99	42.38
	24	0.1596	22.30	8.55	26.49	42.66
	30	0.1812	24.58	7.01	26.18	42.23
Fertilizer Price, FERT	1	0.0246	4.20	0.52	29.37	65.90
	3	0.0371	8.41	1.04	27.02	63.53
	6	0.0510	10.34	3.52	26.05	60.09
	12	0.0885	19.38	6.25	19.80	54.57
	18	0.1240	25.30	4.25	17.19	53.26
	24	0.1460	28.86	3.35	17.41	50.38
	30	0.1580	31.36	3.06	17.03	48.54

AGCHEM at different horizons, what proportions can be attributed to crude price uncertainty? What proportion is attributed to fertilizer price uncertainty? Is AGCHEM's uncertainty attributed to FERT variation to a greater extent than FERT uncertainty is attributed to AGCHEM variation? Analysis of FEV decompositions provides useful insight in answering such questions about the strength of modeled price interrelationships.

A variable's exogeneity is suggested when its FEV is largely attributed to its own variation. Likewise, a variable is highly endogenous to the system when small proportions of its FEV are attributed to its own variation, and large FEV proportions are attributed to the innovations of other variables (Ref. 3).

Crude oil price is largely exogenous to the system. No less than 71% of CRUDE's FEV is self-attributed. Aside from own-variation, CRUDE's FEV is most explained by fertilizer price's uncertainty, which reaches no more than about 17%

Agricultural chemicals price is exogenous at the shorter run horizons of six months or less, at which no less than approximately 70% of AGCHEM's forecast error variance is self-attributed. At horizons exceeding six months, the percentage of AGCHEM's FEV, which is attributed to own-error, drops down to 26% by Step 30. Crude price's uncertainty eventually accounts for about 24.6% of AGCHEM's forecast error variance, a proportion about equal to the 0.24 dynamic multiplier of AGCHEM response to CRUDE changes gleaned above from the impulse response results. Fertilizer price's uncertainty substantially explains AGCHEM's FEV, and this FERT contribution reaches more than 42% at horizons in excess of one year.

Fertilizer price's forecast error variance is more than 60% explained by own variation at early horizons, and these proportions do not drop below about 48%. CRUDE's contributions to FERT's forecast error variance are minor and fail to reach 11% at the earlier horizons of six months or less. Thereafter, CRUDE's contribution to FERT's FEV ranges between 29 and 31% by the final horizons, and is not greatly different from the 0.25 dynamic multiplier of FERT response to CRUDE shocks gleaned above from the impulse response results.

FERT and AGCHEM appear interrelated, because the uncertainty of each feeds into, and explains, the forecast error variance of the other. But this two-way interaction is not equal. FERT uncertainty accounts for up to 43% of AGCHEM's FEV, while FERT has no more than about 29% of its FEV attributed to AGCHEM. So FERT feeds into AGCHEM to a greater extent than AGCHEM feeds into FERT.||

||Recall that this study's VAR orders the four variables as CRUDE to INDCHEM to AGCHEM to FERT. That this ordering generates FEV decompositions which suggest that variable 4 or FERT influences variable 3 or AGCHEM to a greater extent than AGCHEM influences FERT may suggest the appropriateness of the following second ordering where FERT and AGCHEM are in reversed positions: CRUDE, INDCHEM, FERT, AGCHEM. While this study's chosen ordering is justified on grounds of both common sense and theory, other orderings are possible. So we re-did this study using the second ordering. Generally, the results of the VAR with the second ordering were, if not identical, then qualitatively similar. As expected, the impulse responses of both VAR models were identical because the shock variable was not involved in the re-ordered price subset. Also as expected, CRUDE and INDCHEM influenced all four FEV's identically in both models, because CRUDE and INDCHEM were not involved in the reordering. The FEV contributions of AGCHEM and FERT did change, but even these results were similar across models. For instance, FERT was

An interesting coincidence of dynamic relationships emerges from analyses of results of two different VAR econometric techniques: (a) the combination of the impulse response function and the Kloek–Van Dijk Monte Carlo generator, and (b) the FEV decompositions. The impulse response function and the Kloek–Van Dijk method suggest that each percentage of CRUDE change generates 0.24 of a percentage change in AGCHEM over 28 months. The FEV decompositions suggest that by month 30, CRUDE's variation accounts for 24.6% of AGCHEM's variation. The impulse response function and the Kloek–Van Dijk results suggest that each percentage change in CRUDE elicits 0.25 of a percentage change in FERT over 27 months. The FEV decompositions suggest that at the longer run horizons, CRUDE's variation accounts for 29 to 31% of FERT's forecast error variance.

CONCLUSIONS

The dynamic regularities of the monthly movements since 1962 in the four modeled price indices would have agricultural chemical price and fertilizer price respond similarly to a shock in crude oil price. Such movements may be used to characterize the impacts, on agricultural chemical and fertilizer prices, of recent crude oil price movements, insofar as the sample's historical trends reflect an environment not too different from conditions surrounding the CRUDE movements.

Both indices would respond immediately and at a low level for about half a year. Thereafter, AGCHEM and FERT responses would then take similarly shaped, and accelerating patterns through 19 to 21 months after the shock, and would ultimately last for 27 to 28 months. Both oil-based indices would climb/fall, in percentage terms, by about one-quarter of the percentage rise/fall in CRUDE over a period of 27 to 28 months. Within the context of an observed CRUDE increase of 100%, one may expect agricultural chemical and fertilizer prices to rise by 24 to 25% over a period of just over two years. CRUDE shocks spanning more than one month may be analyzed by adding up the concurrent AGCHEM or FERT impulses from CRUDE movements having occurred in different periods. CRUDE increases and decreases originating in different periods are characterized by adding the concurrent positive and negative impulses (of AGCHEM or FERT) into a series of net impulses.

Babula and Somwaru[15] contend that perhaps the two-year nature of the response patterns for AGCHEM and FERT involve the corporate decision lags of new refinery and drilling decisions, as well as the time required to build new petroleum infrastructure. Further, the results capture the long run or average dynamics embedded in the sample, and may differ from effects of specific events. So one should not use these results as forecasts, but rather as general dynamic trend characterizations based on the sample's average dynamic patterns.

A number of dynamic results about the CRUDE/INDCHEM/AGCHEM/FERT price transmission mechanism emerged from analyses of FEV decompositions. CRUDE is highly exogenous to the system. Industrial chemical price contributes in a minor way to the FEV's of AGCHEM and FERT. Fertilizer price feeds into

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rather exogenous at short run horizons and more endogenous at longer run horizons in both models. AGCHEM accounted for minor proportions of FERT's FEV in both models.

agricultural chemicals price to a greater extent than agricultural chemicals price feeds into fertilizer price. The proportions for AGCHEM and FERT that are attributed to CRUDE are similar to the dynamic multipliers of these two prices to oil price changes.

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